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Development and Calibration of a Super Large Scale Gap Test (SLSGT)

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13. ABSTRACT *(Maximum 200 words)*
Numerical simulations of eight inch (203 mm) diameter gap test experiments employing heavily confined donors have been conducted. They reveal that strong convergence of lateral rarefaction waves results in transmitted shocks with latent high pressure regions which exceed the amplitude of the leading edge of the shock wave, and are transmitted into the gap attenuator. Since gap tests are calibrated using TOA measurement of the transmitted shock wave, into the attenuating material, the complex wave structure may lead to erroneous gap pressure assignments in the eight inch gap test. These simulations further indicate that this complex shock wave structure is attributable to the heavy steel case confinement, as donors without it exhibit minimal perturbations from lateral rarefaction. This results in a transmitted shock which is characterized by a smooth time decay profile. Therefore a new eight inch gap test using uncased Comp-B donors was developed, calibrated, and evaluated. TNT and AFX-1100 were used as baseline standard acceptors. The test is designated the "Super Large Scale Gap Test" (SLSGT). Results indicate that the sensitivity of TNT to shock initiation is somewhat greater than previously observed.

14. SUBJECT TERM

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PREFACE

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SECTION I

INTRODUCTION

1. BACKGROUND

An instrumented card gap test was developed by Foster et. al. for investigating the response of explosives to low pressure and long duration shock stimuli (Reference 1).

Figure 1. Eight Inch Gap Test Setup

The test was designed to screen for an energetic materials propensity to detonate or react violently as a result of strong shock. This data is applied to predicting the occurance of shock induced sympathetic detonation of large ordnance such as general purpose bombs. Both donor and acceptor are encased in an eight inch outside diameter steel pipe, with a 0.35 inch thick wall. This test has been used extensively for testing impulse sensitive and large critical diameter explosives by WL/MNME and has been previously calibrated (Reference 2). However, examination using numerical calculational methods revealed that strong lateral rarefaction waves were reflecting back into the shock transmission media Polymethylmethacrylate (PMMA). Convergence of these lateral rarefaction waves results in formation of a latent high pressure

1

region which was greater in amplitude than the leading edge of the transmitted shock. This phenomenon is believed to be attributable to the thick steel case confining the explosive. Since the eight inch gap test was previously calibrated using time of arrival (TOA) measurements of the transmitted shock wave into the attenuating material, the complex wave structure could lead to erroneous gap pressure assignments.

2. NUMERICAL CALCULATIONS

The OTI*HULL hydrocode was used to simulate and analyze the expansion of the explosive products and resulting shock wave propagation of eight inch diameter gap tests. The simulations were performed using an HP model 735 computer. The simulation setup encompassed the initiation train, donor charge and gap attenuating material, and is depicted in Figure 2. A total of 16 stations placed along the centerline of the axis of wave propagation, at 12.7 mm increments were analyzed.
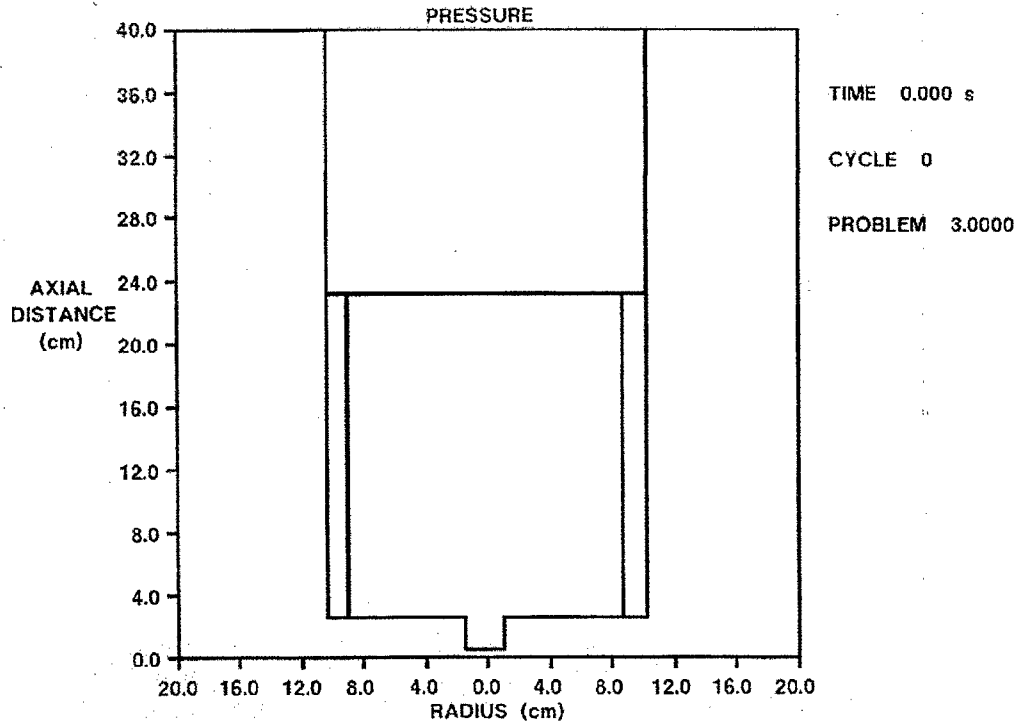
Figure 2. Eight Inch Gap Test Simulation Setup 2-D View

The detonation wave propagation at 20 and 40 usec is depicted in Figures 3 and 4. Strong lateral waves are observed reflecting from the steel case back into the explosive products in Figure 3, and converging in the center of the explosive products in Figure 4.

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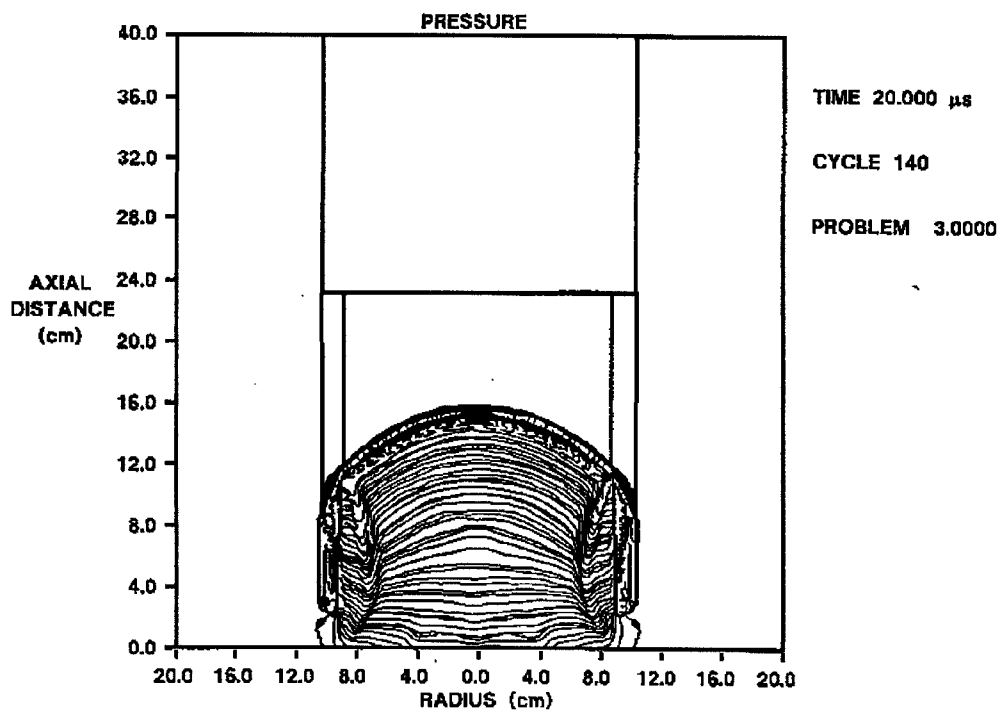
Figure 3. Eight Inch Gap Test Simulation 2-D View at 20 usec Elapsed Time
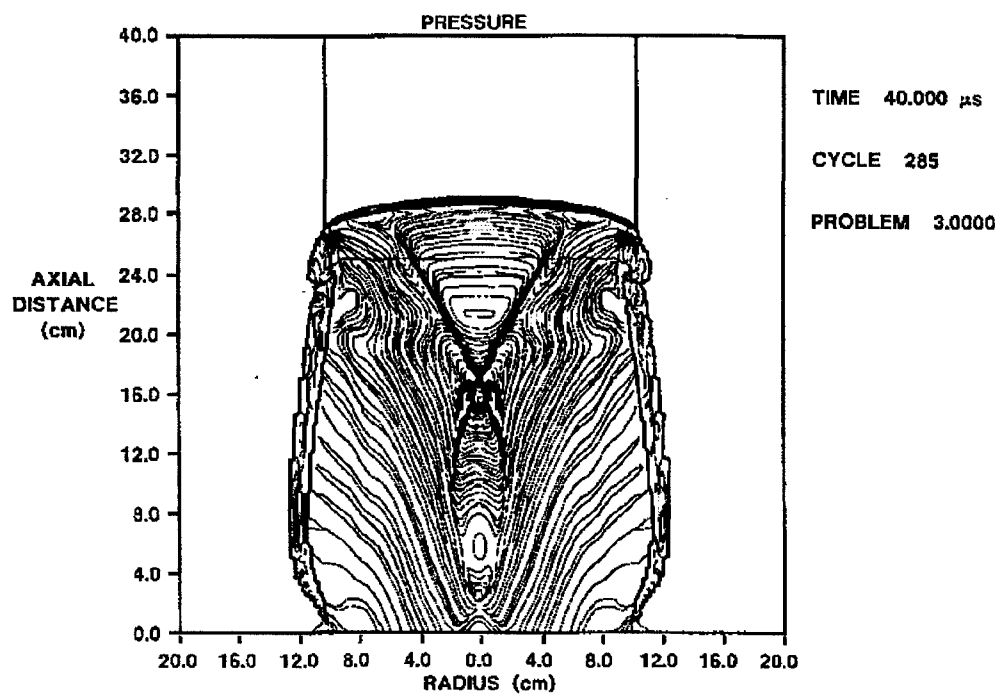
Figure 4. Eight Inch Gap Test Simulation 2-D View at 40 usec Elapsed Time

3

The pressure time profile of the shock propagation in the PMMA at stations 8 and 15 positioned 3.5 and 7 inches, respectively, from the explosive PMMA interface are depicted in Figures 5 and 6. A complex dual peak wave is observed at station 8 where the latent peak exceeds the amplitude of the leading edge of the primary pulse. At station 15 these peaks have coalesced to a large degree, however the secondary peak still exceeds the amplitude of the leading edge of the primary pulse.
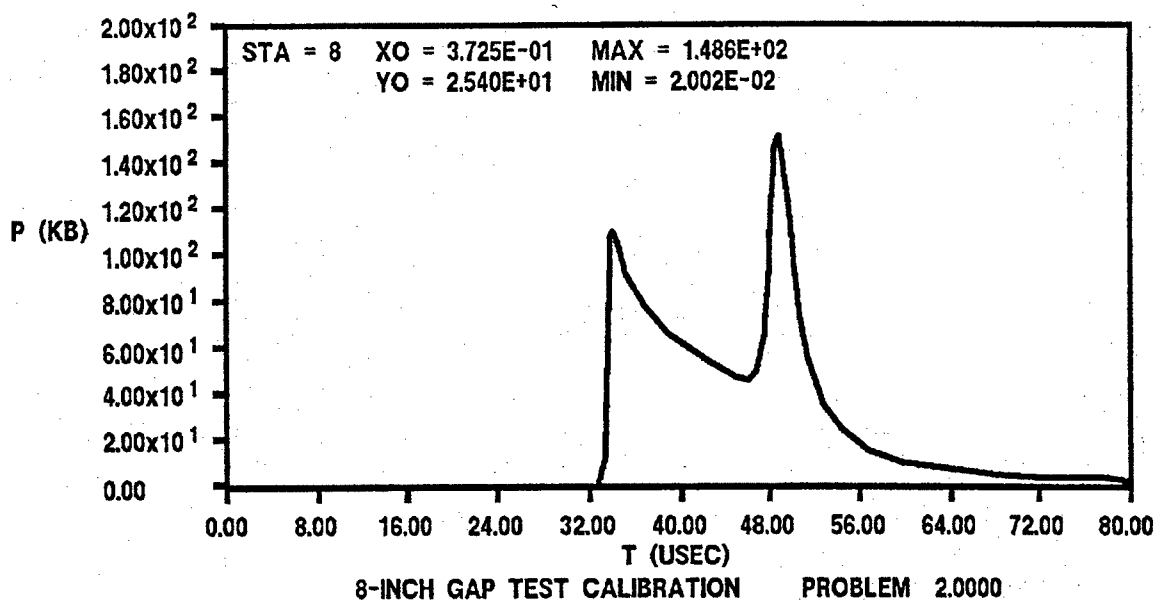
Figure 5. Eight Inch Gap Test Simulation Pressure Time Profile at Station 8
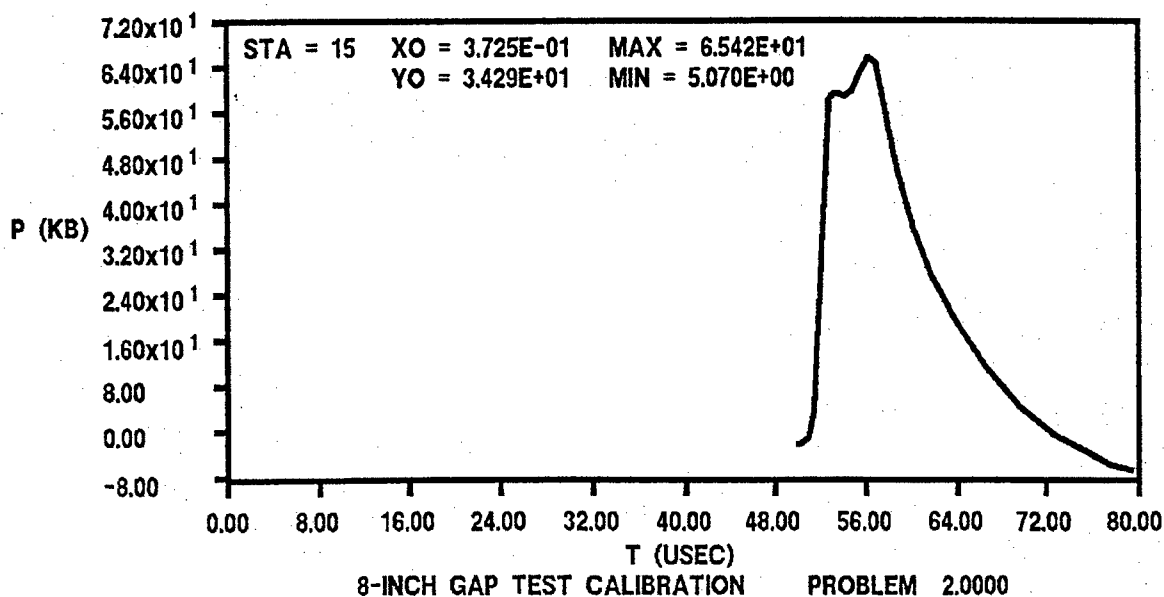
Figure 6. Eight Inch Gap Test Simulation Pressure Time Profile at Station 15

4

Identical calculations were also performed except that the confining donor casewall was removed from the physical setup, which is illustrated in Figure 7.
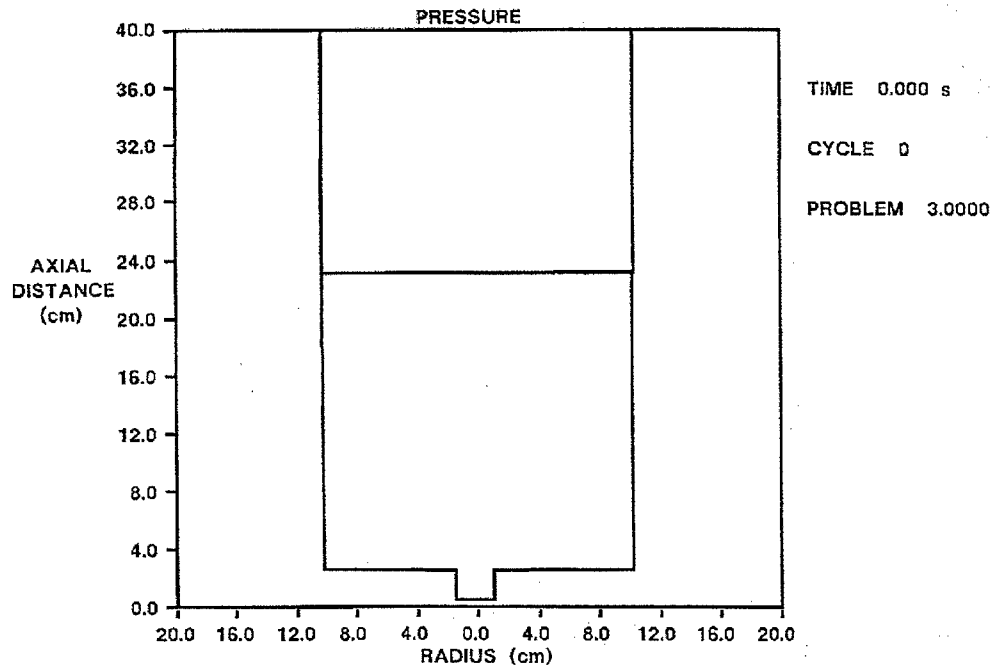
Figure 7. Unconfined Eight Inch Gap Test Simulation Setup 2-D View

The detonation wave propagation at 20 and 40 usec are illustrate (see figures 8 and 9). In this configuration the expanding explosive products are free from any significant perturbation from lateral waves throughout their expansion and propagation.
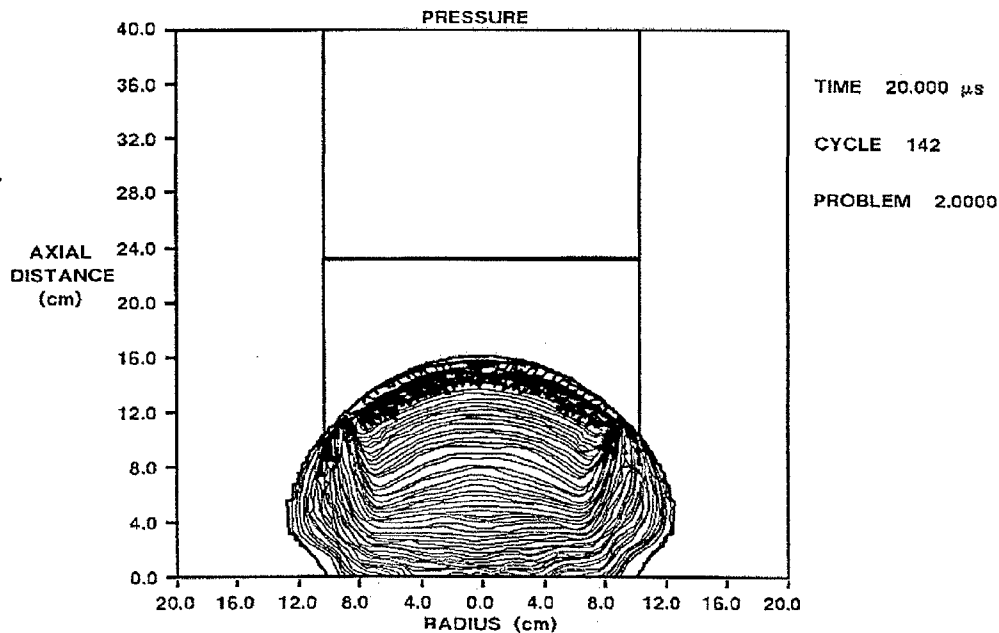
Figure 8. Unconfined Eight Inch Gap Test Simulation 2-D View at 20 usec Elapsed Time

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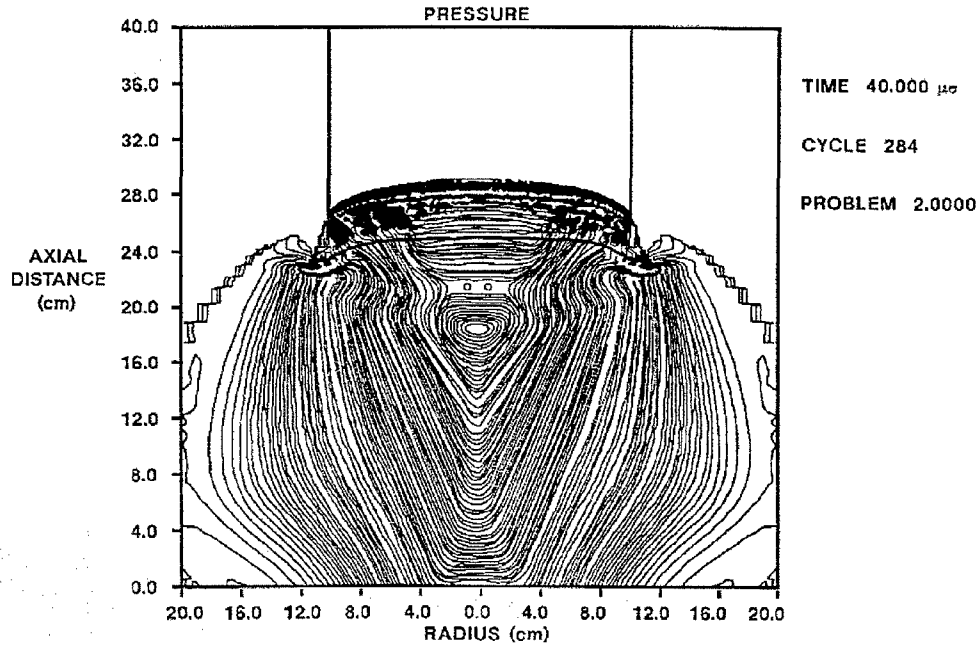
Figure 9. Unconfined Eight Inch gap Test Simulation 2-D View at 40 usec Elapsed Time

The pressure time profile of the shock propagation in the PMMA at stations 8 and 15 are again illustrated (see Figure 10 and 11). A simple waveform is observed where the leading edge displays a sharp rise followed by an exponential decay.
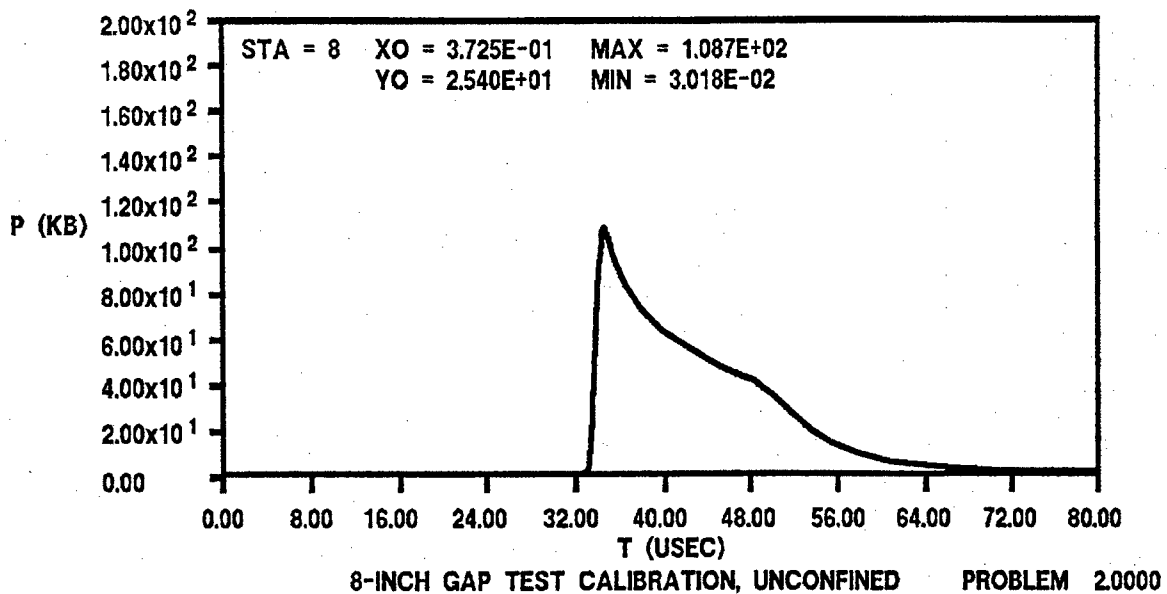
Figure 10. Unconfined Eight Inch Gap Test Simulation Pressure Time Profile at Station 8

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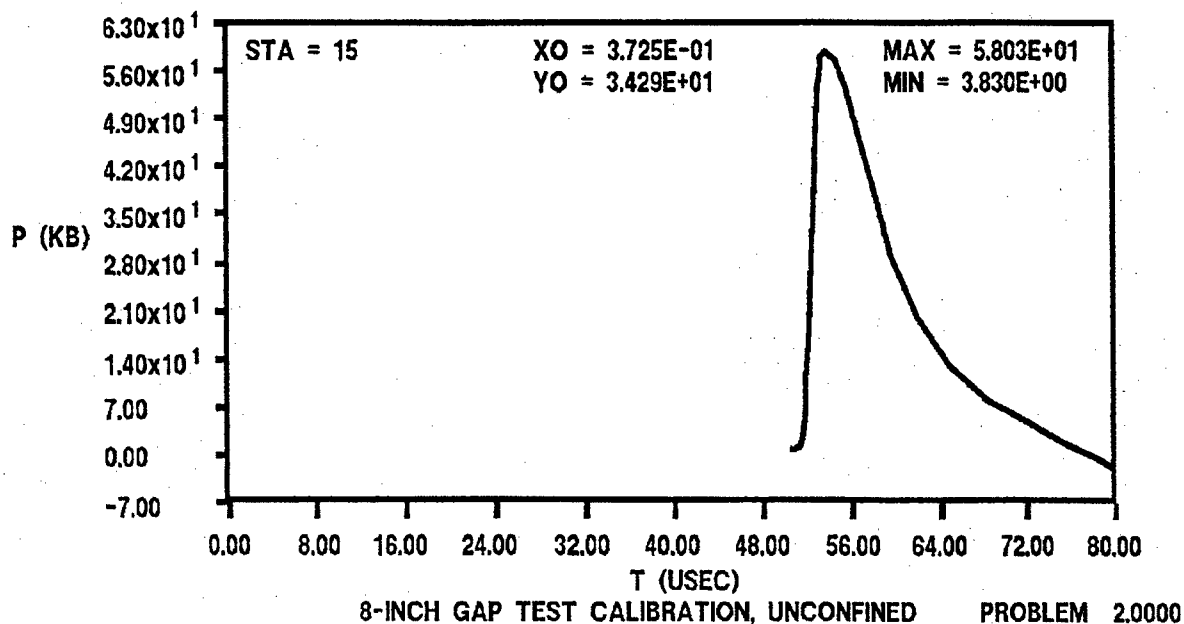
Figure 11. Unconfined Eight Inch Gap Test Simulation Pressure Time Profile at Station 15

3. OBJECTIVE

The objective of this study is to design, develop, calibrate and evaluate a Super Large Scale Gap Test which has minimal influence from lateral rarefactions and complex input shock wave structure.

EXPERIMENTAL PROCEDURES

1. SUPER LARGE SCALE GAP TEST CALIBRATION SETUP

To facilitate comparison with the existing tests, an experimental design analogous to that of the Naval Ordnance Laboratory (NOL) Large Scale Gap Test (LSGT) (Reference 3) and the Expanded Large Scale Gap Test (ELSGT) (Reference 4) was chosen. These tests are used for measuring explosive sensitivity to shock wave pressure and duration, and differ primarily in charge diameter. A series of three calibration experiments were performed. The Comp-B donors charges, 203 mm x 203 mm, were loaded using melt cast processing. The average density of these charges was 1.68+/-0.01 gm/cm^3. The donors were initiated using a detonation train consisting of one 50.8 mm x 50.8 mm Comp-B booster, one 25.4 mm x 25.4 mm A-5 pellet, and an RP-83 explosive bridgewire detonator. The donor was abutted to six PMMA disks 203 mm in diameter by 50.8 or 76.2 mm thick, which were precision machined to a tolerance of +/- 0.005 inch. Two of the tests utilized 24 piezoelectric pins and one used 20 pins. All pins were stationed at 12.7 or 25.4 mm intervals, from 0 to 400 mm along the axis of the PMMA cylinder. The pins were embedded into the PMMA to within 0.125 inch of the centerline, and radially spaced to reduce their intrusive effects on the response of down stream pins. A Tektronics RTD-710A waveform digitizer with 10 nanosecond resolution was used to record shock wave TOA. The signals were differentiated to obtain the shock velocity, U_s, at each station (equation 1),

$$U_s = dx / dt \qquad (1)$$

where U_s is the incremental shock velocity, dx is the change in distance in millimeters (mm) and dt is the change in time in microseconds (usec).
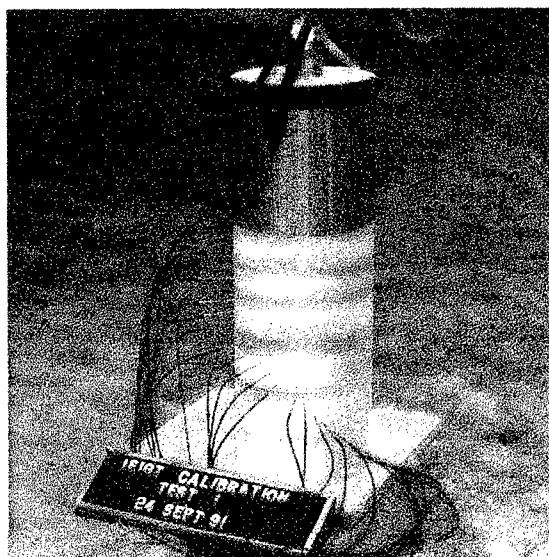
Figure 12. SLSGT Calibration Setup

2. CALIBRATION DATA ANALYSIS

Using the equation of state for PMMA derived by Jaffee, et, al., (Reference 5), the particle velocity was derived for a specific shock velocity (equation 2,3)

$$u_P = (Us - 2.59)/1.52, \quad U_s \geq 3 \qquad (2)$$

where U_s is the shock velocity in mm/usec, and u_p is the particle velocity in mm/usec. Treatment of the data below a U_s of 3.0 mm/usec required use of an alternate Hugoniot due to the bend in the Hugoniot curve below this region, shown by Erkman (Reference 6). However to obtain the Hugoniot for this region, the Jaffe data was separately fit with a second linear equation for the points where U_s was less than 3.0 mm/usec, resulting in equation 3.

$$u_P = (U_s - 2.44)/2.16, \quad U_s \leq 3 \qquad (3)$$

The relation derived from the conservation of momentum equation (equation 4) was used to derive the peak pressure,

$$P = \rho_o U_s u_p \qquad (4)$$

where P is the peak pressure in kilobars (kbar) and ρ_o is the density of the PMMA (1.185 gm/cm^3). The pressure data was first smoothed using a Lowess smoothing algorithm with an f parameter of 0.1. The Lowess algorithm is a locally weighted regression which performs a full least-squares fit for each data point. The smoothed data was then fit using least squares methods to a number of non-linear forms, the best fitting form was equation 5.

$$y^{-1} = a + bx + cx^2 + dx^3 + ex^4 \qquad (5)$$

where a, b, c, d and e are the fit coefficients, the y variable represents pressure in kbar, and the x variable represents distance in the PMMA in inches. The best fit to the data is defined in equation 6,

$$P = 1/4.7926052E^{-3} + 5.6421937E^{-3}X - 1.9701727E^{-3}X^2 + 3.4845368E^{-4}X^3 + 1.2413159E^{-5}X^4 \qquad (6)$$

with a correlation coefficient for multiple determination of 0.9973 obtained on the smoothed data. Equation 6 was then used to generate the final pressure displacement curve and calibration table found in Appendix A. The calibration curve is illustrated in Figure 18.

A correlation was made with Los Alamos data using their selected Hugoniot chart which depicts Hugoniots for various explosives and inert materials to obtain the pressure in the PMMA at the Comp B/PMMA interface. Intersection points between reactive and inert Hugoniots provides interface pressure and particle velocity for any two materials. The Los Alamos data for Comp B intersecting with PMMA listed a particle velocity of 2.65 km/sec with a matching pressure of 210 kbar. Since data was not obtained within the first inch of the attenuator, particle velocity was plotted and extrapolated out to the Comp B/PMMA interface. The data was fit with a fifth order polynomial which had a 97% goodness of fit.

1 Eqn 221 $y=(a+cx+ex^2+gx^3+ix^4+kx^5)/(1+bx+dx^2+fx^3+hx^4+jx^5)$ r2=0.999967811
a=0.18608929 b=−8.3124193 c=28.185965 d=15.128211 e=−225.34983 f=−6.4000284
g=288.38226 h=−0.45215336 i=107.06797 j=0.049180084 k=−149.15233
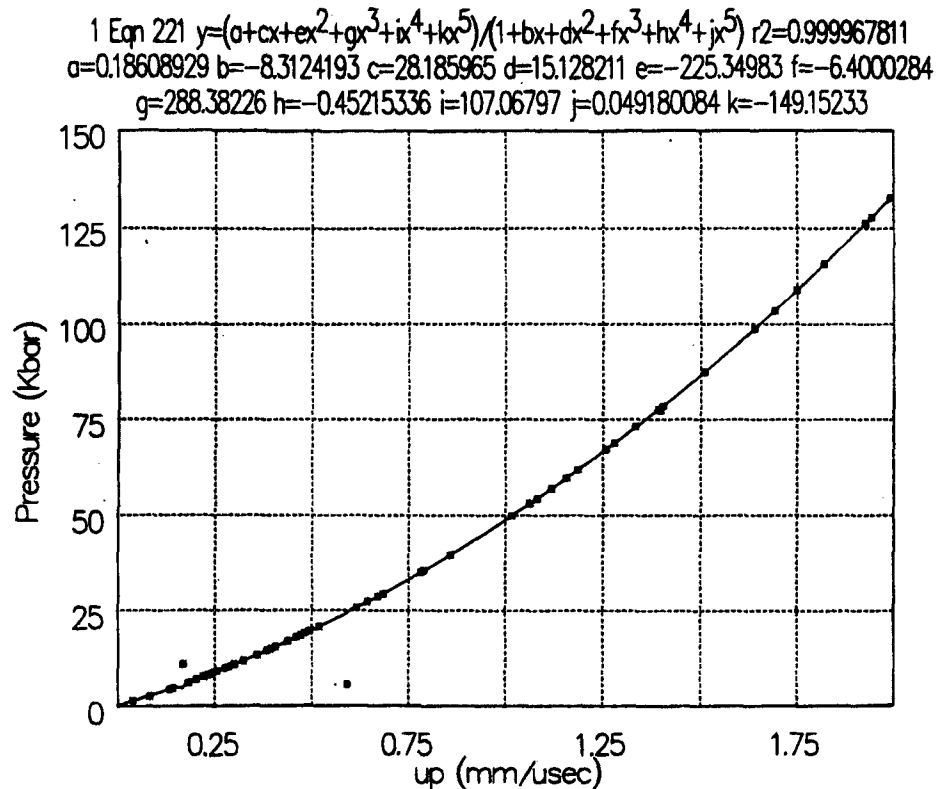
Figure 13. Hugoniot Plot

Using this equation the particle velocity of 2.65 km/sec was input as the x variable and the calculated y variable pressure was 208 kbars. There is approximately 1% difference in the LANL data.

3. SUPER LARGE SCALE GAP TEST SETUP

The new test method designated the Super Large Scale Gap Test (SLSGT), differs from the original eight inch gap test in three ways; first, the item will be positioned vertically to the ground, second, the acceptor charge is positioned on top of a piece of mild steel and third the donor is not confined in a thick steel case. A diagram of the SLSGT is illustrated in Figure 15.

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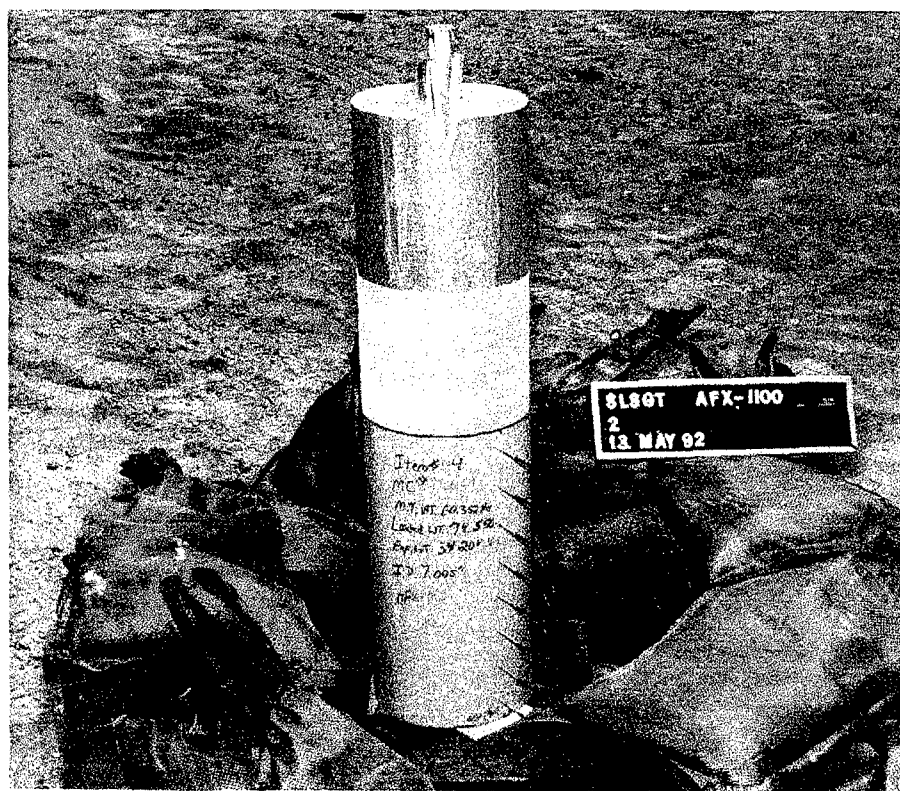
Figure 14. SLSGT Setup

Assessment of reaction severity is then obtained in three forms. First, the shock velocity in the acceptor is determined by placing piezoelectric pins at 50.8 mm intervals along the centerline of the charge. The pins generate a time of arrival signal upon of the shock/detonation wave. The data were recorded on a Tektronics 710A waveform digitizer, and differentiated to obtain the wave velocity (Equation 6),

$$Vi = dx \, / \, dt \quad (6)$$

where V_i is the incremental velocity in mm/usec, dx is the change in distance in mm, and dt is the change in time in usec. Secondly, the casewall fragment size and shape is examined. The size and shape of the casewall fragments is dominated by the reaction rate of the acceptor explosive. If the acceptor charge detonates then the fragments will be small and have a distinctive shear plane. If the item experiences a decaying reaction, the casewall will be broken into large pieces. If no explosive reaction occurs, the acceptor can will be recovered typically in one piece. Finally the witness plate is observed for damage. The witness plate is backup data. If the explosive detonates a hole will be punched in the center of the plate the same diameter as the acceptor charge. If it experiences a decaying reaction the plate will exhibit plastic deformation. Figure 16 shows a witness plate after a detonation. A large hole has been punched in the plate.

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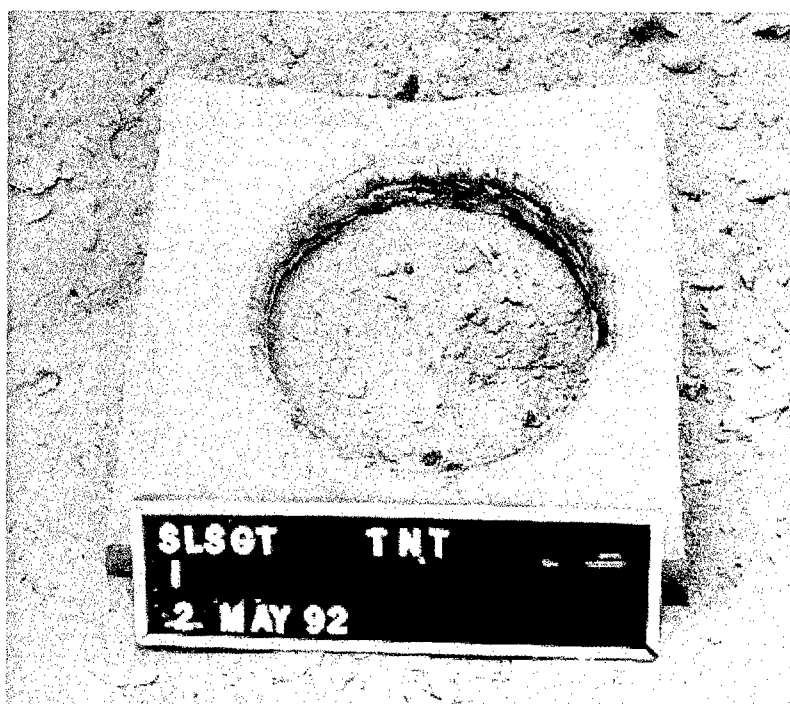
Figure 15. Witness Plate Post Test Detonation

EXPERIMENTAL RESULTS

1. CALCULATED CALIBRATION

The calculated pressure versus distance data for both the eight inch gap and SLSGT calibration is listed in Table 1. Data for both the leading and trailing peak are listed for the eight inch Gap test. A Graphic depiction of the data is shown in Figure 16.

TABLE 1. SLSGT AND 8 INCH GAP TEST CALCULATED CALIBRATION DATA

Station #	Distance (in)	8 Inch Gap Pressure (kbar) Leading peak	8 Inch Gap Pressure (kbar) Trailing Peak	SLSGT Pressure (kbar)
1	0.100	130	148	130
2	0.500	107	125	113
3	1.000	99	108	98
4	1.500	87	96	87
5	2.000	79	87	79
6	2.500	73	80	73
7	3.000	69	74	68
8	3.500	64	70	64
9	4.000	61	67	61
10	4.500	64	-	58
11	5.000	62	-	54
12	5.500	60	-	49
13	6.000	56	-	43
14	6.500	50	-	37
15	7.000	44	-	32
16	8.000	34	-	24
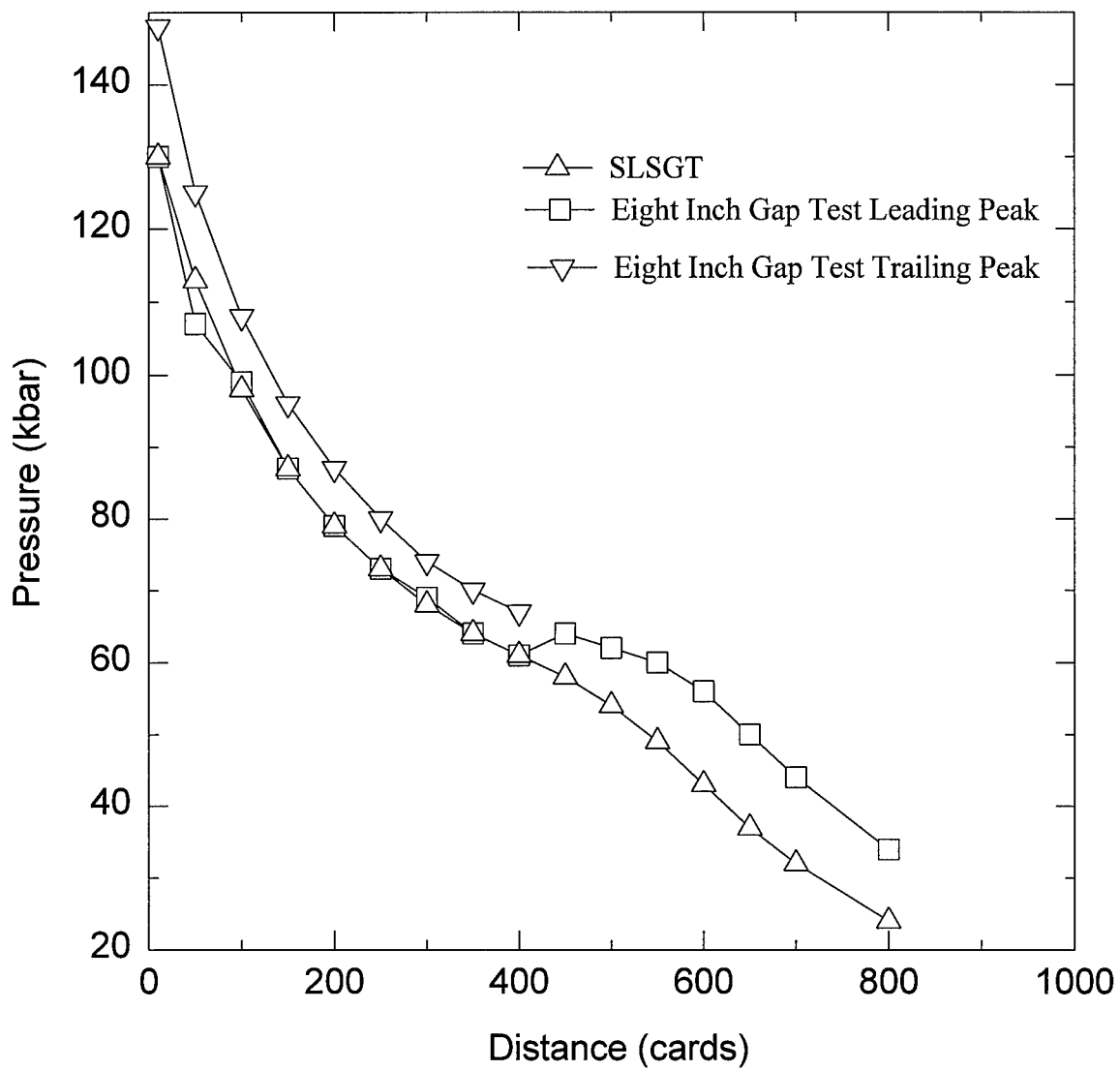
Figure 16. SLSGT and Eight Inch GAP Test Calculated Calibration Data

2. SUPER LARGE SCALE GAP TEST MEASURED CALIBRATION

The data obtained in the measured calibration of the SLSGT is listed in Tables 2 and 3. A graphic representation is shown in Figures 17 and 18.

TABLE 2. SLSGT TIME OF ARRIVAL, SHOCK & PARTICLE VELOCITY DATA

Distance (in)	Test 1			Test 2			Test 3		
	TOA (usec)	U_s (mm/usec)	u_p (mm/usec)	TOA (usec)	U_s (mm/usec)	u_p (mm/usec)	TOA (usec)	U_s (mm/usec)	u_p (mm/usec)
0.500	44.51	--	--	44.78	--	--	0.000	--	--
1.000	46.79	5.570	1.9605	47.04	5.6195	1.9931			
1.500	49.08	5.534	1.9368	49.46	5.2479	1.7486	5.062	5.000	1.5855
2.000									
2.500	54.09	5.075	1.6349	54.46	5.0800	1.6382	9.971	5.174	1.700
3.000	56.79	4.704	1.3908	57.14	4.7388	1.4137			
3.500	59.35	4.951	1.5533	59.9	4.6014	1.3233	15.19	4.8696	1.4997
4.000									
4.500	65.24	4.312	1.1329	65.54	4.5035	1.2589	20.71	4.5998	1.3222
5.000	68.13	4.394	1.1868	68.56	4.2053	1.0627			
5.500	71.21	4.123	1.0086	71.56	4.2333	1.0811	26.77	4.192	1.054
6.000									
6.500	77.85	3.825	0.8125	78.08	3.8957	0.8590	33.21	3.9429	0.8901
7.000	81.39	3.588	0.6566	81.64	3.5674	0.6430			
7.500	84.96	3.557	0.6362	85.46	3.3246	0.4833	40.34	3.5604	0.6384
8.000	88.75	3.351	0.5007	89.22	3.3777	0.5182			
8.500	92.64	3.265	0.4441	93.06	3.3073	0.4719	48.32	3.1842	0.3909
9.000									
9.500	100.26	3.333	0.4888	101.16	3.1358	0.3591	--	--	--
10.000	104.59	2.933	0.2282	105.52	3.0825	0.3240			
10.500	109.24	2.731	0.1343	109.52	2.9953	0.2571	65.20	3.0105	0.2766
11.000	113.25	3.167	0.3796	113.74	3.0095	0.2760			
11.500	117.51	2.981	0.2505	117.38	3.4890	0.5914	73.32	3.124	0.3513
12.000									
12.500	126.12	2.950	0.2361	126.44	2.8035	0.1683	82.07	2.905	0.2153
13.000	130.10	3.265	0.4441	129.86	3.7135	0.7391			
13.500	133.62	3.608	0.6697	134.02	3.0529	0.3045	90.58	2.983	0.2514
14.000	138.52	2.592	0.0704	--	--	--			
14.500	143.20	2.714	0.1269	142.15	3.1250	0.3520	99.63	2.807	0.1699
15.000									
15.500							108.45	2.879	0.2032

TABLE 3. SLSGT PRESSURE CALIBRATION DATA

Distance (in)	Pressure Test 1 (kbar)	Pressure Test 2 (kbar)	Pressure Test 3 (kbar)
1.000	127.01	108.74	
1.500	98.32	98.61	93.94
2.000			
2.500	77.52	79.38	104.23
3.000	91.13	72.15	
3.500	57.89	67.18	86.54
4.000			
4.500	61.80	52.96	72.07
5.000	49.28	54.23	
5.500	36.83	39.66	52.36
6.000			
6.500	27.92	27.18	41.59
7.000	26.82	19.04	
7.500	19.88	20.74	26.94
8.000	17.18	18.49	
8.500	19.31	13.34	14.75
9.000			
9.500	7.93	11.84	--
10.000	--	9.12	
10.500	--	9.84	9.87
11.000	8.85	--	
11.500	8.25	5.59	13.00
12.000			
12.500	--	--	7.41
13.000	--	--	
13.500	2.16	--	8.89
14.000	4.08	--	
14.500	--	--	5.66
15.000			
15.500			6.93
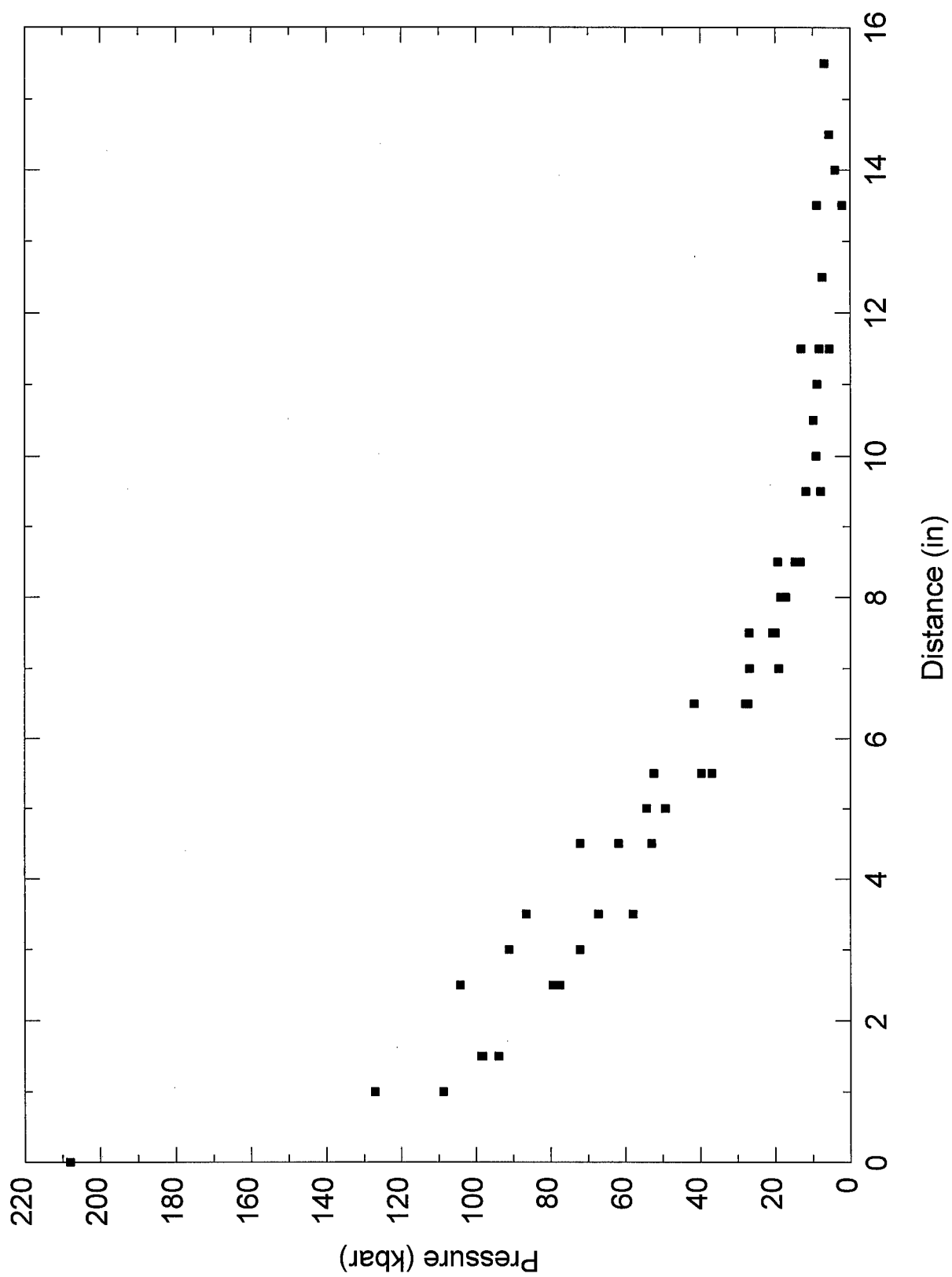
Figure 17. SLSGT Measured Calibration Data

Rank 3 Eqn 6112 $y^{-1}=a+bx+cx^2+dx^3+ex^4$

r^2=0.99734797 DF Adj r^2=0.9970466 FitStdErr=2.2226033 Fstat=4230.777

a=0.0047926052 b=0.0056421937 c=-0.0019701727

d=0.00034845368 e=-1.2413159e-05
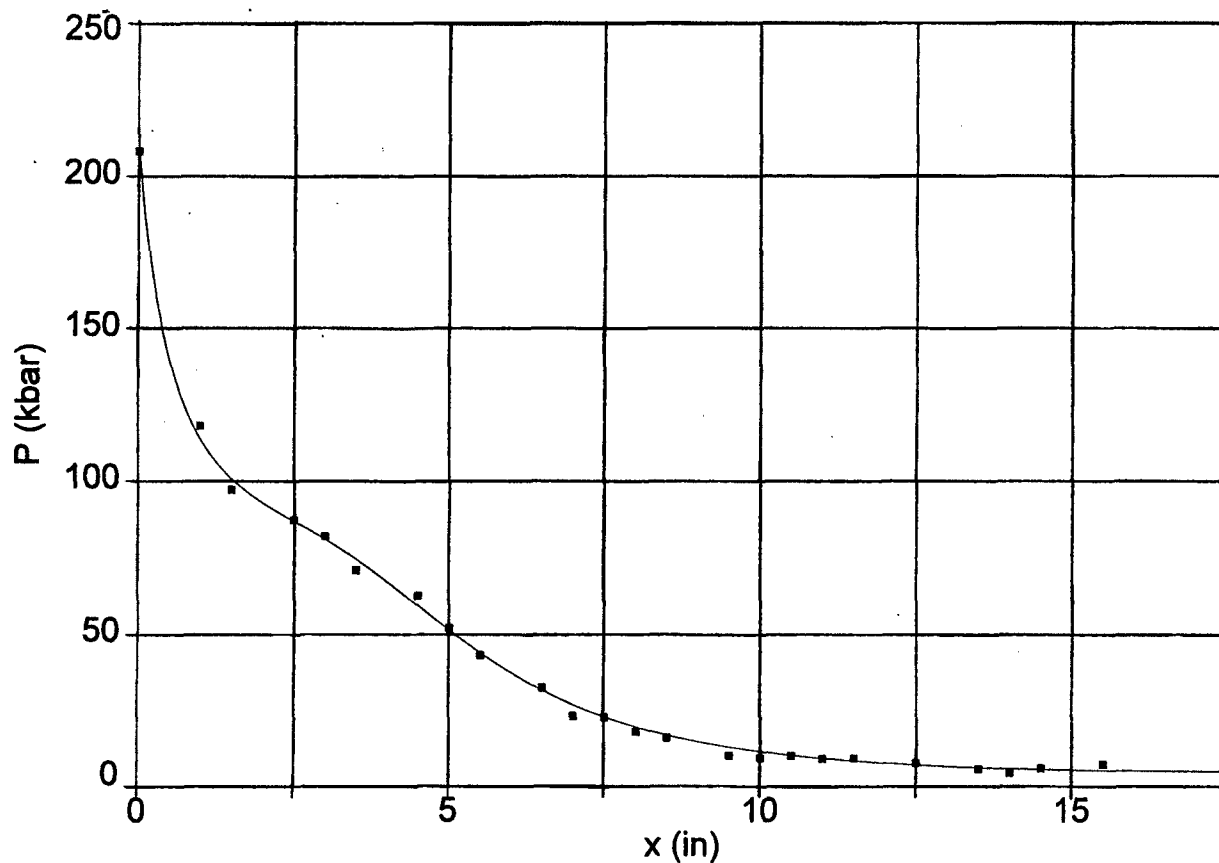
Figure 18. SLSGT Measured Calibration Curve

3. SUPER LARGE SCALE GAP TEST BASELINE SERIES.

The results of SLSGT experiments conducted on TNT and AFX-1100 II are listed in Table 4.
The gap pressure (P_g) for TNT was 7.5 kbar and that of AFX-1100 II was 31.5 kbar.

TABLE 4. SLSGT RESULTS

		GO		NOGO	
Explosive	Density (gm/cm^3)	Distance (in)	Pressure (kbar)	Distance (in)	Pressure (kbar)
TNT	1.58	12	7.5	13	6.4
AFX-1100	1.52	6.5	31.5	6.75	29.0

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SECTION IV

DISCUSSION

In Figure 19 the calibration curves of the Super Large Scale Gap Test and the original Eight Inch Diameter Heavily Confined Card Gap Test are illustrated for comparison.
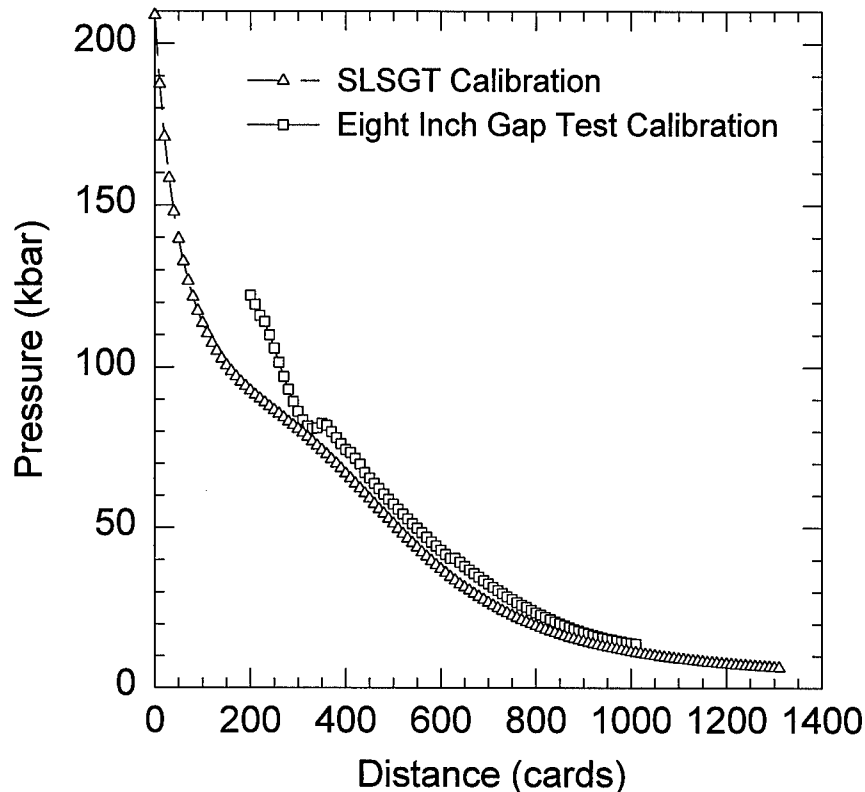
Figure 19. SLSGT Eight Inch Gap Test Measured Calibration Comparison

The comparison of measured calibration curves illustrated in Figure 19 clearly shows that the difference in pressure for a given distance in the PMMA for the two methods is small below a peak pressure of 100 kbar. Hence the major difference between the two methods, indicated by the numerical calculations, is that the confined test produces a greater impulse in the donor charge due to lateral rarefactions. This results in a longer positive phase duration of the resulting pressure pulse in the PMMA. The positive phase duration the eight inch gap test from stations 8 to 15 varied from 32 to 22 microseconds in accordance with the calculation while that for the SLSGT showed little change in duration over the same region, 22 microseconds at station 8 and 21 microseconds at station 15. This is attributable to the generation of a duplex peak in the eight inch gap test and the overtaking of the leading peak by the trailing one and their coalescence into one peak. Coalescence is completed by a peak pressure of 100 kbar. Hence over the pressure region where the sensitivity of most explosives is defined little difference between the two

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methods is observed. However removing the donor confinement eliminates the duplex wave structure of the input shock wave and results in a calibration that is analogous to the NOL LSGT and ELSGT with a much longer positive phase duration and total impulse.

The SLSGT results for TNT and AFX-1100 II show that both materials are somewhat more sensitive than that previously reported using the Eight inch Gap Test. This greater sensitivity is primarily a result of the improved measurement technique.

TABLE 4. GAP TEST COMPARISON

	Gap Pressure (kbar)	
	Eight Inch Gap Test	SLSGT
TNT	14	7.5
AFX-1100 II	43	31.5

SECTION V

CONCLUSIONS & RECOMMENDATIONS

1. CONCLUSIONS

Heavy steel confinement of Gap test donors in the eight inch gap test results in strong convergence of lateral rarefaction waves in the shock transmitting medium. These converging rarefactions result in a complex wave structure in the transmitted shock input to the acceptor. Unconfined donors eliminate problems associated with these strong lateral rarefactions and resulting input shocks transmitted to the acceptor are characterized by a smooth pressure decay profile. The SLSGT, because of its unconfined donor charges and resulting smooth pressure decay profile, provides finer discrimination for long pulse duration shocks and improved correlation to other standard gap test of smaller diameter.

2. RECOMMENDATIONS

The SLSGT is recommended for used in place of the eight inch gap test for measuring shock sensitivity of explosives at large diameters whenever practical.

SUPER LARGE SCALE GAP TEST

RP-2 detonator

Comp A-5 25.4 mm x 25.4 mm

Comp-B Booster 50.8 mm x 50.8 mm

Comp-B Donor 203 mm x 203 mm

Piezoelectric Pins 25.4 mm apart

Acceptor Explosive Cylinder 203.2 mm O.D./177.8 mm I.D. 406.4 mm long

Acceptor Explosive 177.8 mm x 406.4 mm

Witness Plate 3.8 x 40.6 x 40.6 cm mild steel
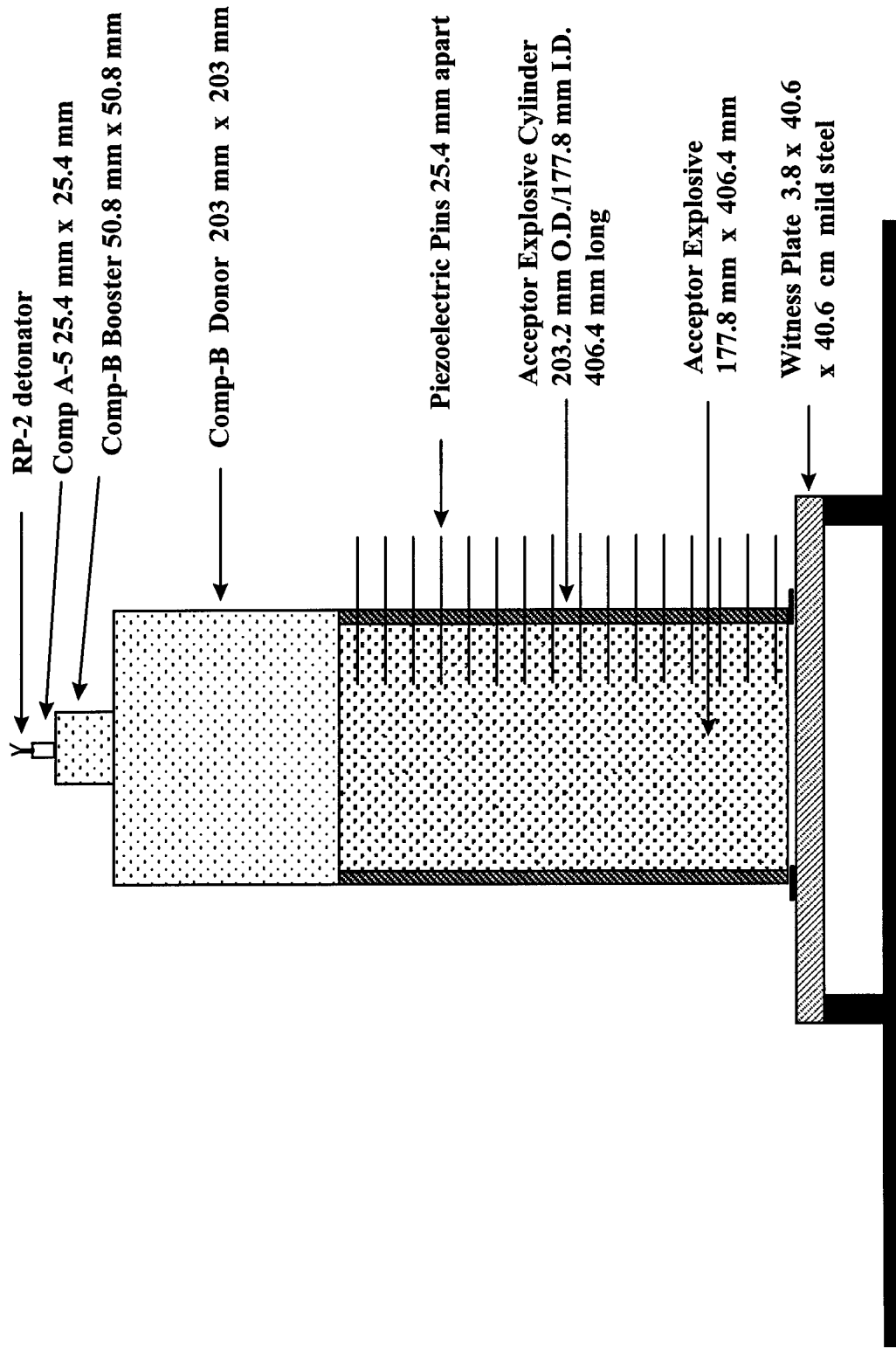
APPENDIX A
CALIBRATION TABULATION OF SLSGT

23/24 (Blank)

SUPER LARGE SCALE GAP TEST CALIBRATION

(Distance in inches is sum of number in first column plus number in hundredths across top.
Pressure is in kbar)

Pressure in kbar

Inches	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	208.6	206.2	203.9	201.6	199.4	197.2	195.2	193.1	191.1	189.2
0.1	187.4	185.5	183.8	182.0	180.3	178.7	177.1	175.5	174.0	172.5
0.2	171.1	169.7	168.3	166.9	165.6	164.3	163.1	161.8	160.6	159.4
0.3	158.3	157.2	156.1	155.0	153.9	152.9	151.9	150.9	150.7	149.0
0.4	148.0	147.1	146.2	145.3	144.4	143.6	142.8	142.0	141.1	140.3
0.5	139.6	138.9	138.1	137.4	136.7	136.0	135.2	134.6	133.9	133.2
0.6	132.6	132.0	131.3	130.7	130.1	129.5	129.0	128.4	127.8	127.2
0.7	126.7	126.2	125.6	125.1	124.6	124.1	123.6	123.1	122.6	122.1
0.8	121.7	121.2	120.6	120.3	119.9	119.4	119.0	118.6	118.2	117.8
0.9	117.4	117.0	116.6	116.2	115.8	115.4	115.1	114.7	114.3	114.0
1.0	113.6	113.3	112.9	112.6	112.3	112.0	111.6	111.3	111.0	110.7
1.1	110.4	110.1	109.8	109.5	109.2	108.9	108.6	108.3	108.0	107.8
1.2	107.5	107.2	107.0	106.7	106.4	106.2	105.9	105.7	105.4	105.2
1.3	105.0	104.7	104.5	104.2	104.0	103.8	103.6	103.3	103.1	103.0
1.4	102.7	102.5	102.3	102.0	101.9	101.6	101.4	101.2	101.0	100.8
1.5	100.6	100.4	100.2	100.1	99.9	99.7	99.5	99.3	99.1	99.0
1.6	98.8	98.6	98.4	98.3	98.1	98.0	97.8	97.6	97.4	97.3
1.7	97.1	97.0	96.8	96.6	96.4	96.3	96.1	96.0	95.8	95.7
1.8	95.5	95.4	95.2	95.1	94.9	94.8	94.6	94.5	94.4	94.2
1.9	94.1	93.9	93.8	93.7	93.5	93.4	93.2	93.1	93.0	92.8
2.0	92.7	92.6	92.4	92.3	92.2	92.1	91.9	91.8	91.7	91.5
2.1	91.4	91.3	91.2	91.0	90.9	90.8	90.7	90.5	90.4	90.3
2.2	90.2	90.0	89.9	89.8	89.7	89.6	89.4	89.3	89.2	89.1
2.3	89.0	88.8	88.7	88.6	88.5	88.4	88.2	88.1	88.0	87.9
2.4	87.8	87.7	87.6	87.4	87.3	87.2	87.1	87.0	86.8	86.7
2.5	86.6	86.5	86.4	86.3	86.2	86.0	85.9	85.8	85.7	85.6
2.6	85.5	85.3	85.2	85.1	85.0	84.9	84.8	84.6	84.5	84.4
2.7	84.3	84.2	84.1	83.9	83.8	83.7	83.6	83.5	83.4	83.2
2.8	83.1	83.0	82.9	82.8	82.6	82.5	82.4	82.3	82.2	82.0
2.9	81.9	81.8	81.7	81.7	81.4	81.3	81.2	81.1	81.0	80.8
3.0	80.7	80.6	80.5	80.3	80.2	80.1	80.0	79.8	79.7	79.6
3.1	79.5	79.3	79.2	79.1	79.0	78.8	78.7	78.6	78.4	78.3
3.2	78.2	78.1	77.9	77.8	77.7	77.5	77.4	77.3	77.1	77.0

3.3	76.9	76.7	76.6	76.5	76.4	76.2	76.1	75.9	75.8	75.7
3.4	75.5	75.4	75.3	75.1	75.0	74.8	74.7	74.6	74.4	74.3
3.5	74.2	74.0	73.9	73.7	73.6	73.5	73.3	73.2	73.0	72.9
3.6	72.8	72.6	72.5	72.3	72.2	72.0	71.9	71.8	71.6	71.5
3.7	71.3	71.2	71.0	70.9	70.7	70.6	70.4	70.3	70.1	70.0
3.8	69.8	69.7	69.6	69.4	69.2	69.1	69.0	68.8	68.6	68.5
3.9	68.3	68.2	68.0	67.9	67.8	67.6	67.4	67.3	67.1	67.0
4.0	66.8	66.7	66.5	66.4	66.2	66.1	65.9	65.8	65.6	65.4
4.1	65.3	65.1	65.0	64.8	64.7	64.5	64.4	64.2	64.0	63.9
4.2	63.7	63.6	63.4	63.3	63.1	63.0	62.8	62.6	62.5	62.3
4.3	62.2	62.0	61.8	61.7	61.5	61.4	61.2	61.0	60.9	60.7
4.4	60.6	60.4	60.3	60.1	60.0	59.8	59.6	59.5	59.3	59.2
4.5	59.0	58.8	58.7	58.5	58.4	58.2	58.0	57.9	57.7	57.6
4.6	57.4	57.2	57.1	56.9	56.8	56.6	56.5	56.3	56.1	56.0
4.7	55.8	55.7	55.5	55.4	55.2	55.0	54.9	54.7	54.6	54.4
4.8	54.3	54.1	53.9	53.8	53.6	53.5	53.3	53.2	53.0	52.8
4.9	52.7	52.5	52.4	52.2	52.1	51.9	51.8	51.6	51.5	51.3
5.0	51.2	51.0	50.8	50.7	50.5	50.4	50.2	50.1	49.9	49.8
5.1	49.6	49.5	49.3	49.2	49.3	48.9	48.7	48.6	48.4	48.3
5.2	48.1	48.0	47.8	47.7	47.5	47.4	47.2	47.1	46.9	46.8
5.3	46.6	46.5	46.4	46.2	46.1	45.9	45.8	45.6	45.5	45.3
5.4	45.2	45.0	44.9	44.8	44.6	44.5	44.3	44.2	44.1	43.9
5.5	43.8	43.6	43.5	43.4	43.2	43.1	42.9	42.8	42.7	42.5
5.6	42.4	42.2	42.1	42.0	41.8	41.7	41.6	41.4	41.3	41.2
5.7	41.0	40.9	40.8	40.6	40.5	40.4	40.2	40.1	40.0	39.8
5.8	39.7	39.6	39.4	39.3	39.2	39.1	38.9	38.8	38.7	38.6
5.9	38.4	38.3	38.2	38.0	37.9	37.8	37.7	37.5	37.4	37.3
6.0	37.2	37.0	36.9	36.8	36.7	36.6	36.4	36.3	36.2	36.1
6.1	36.0	35.8	35.7	35.6	35.5	35.4	35.2	35.1	35.0	34.9
6.2	34.8	34.7	34.6	34.4	34.3	34.2	34.1	34.0	33.9	33.8
6.3	33.6	33.5	33.4	33.3	33.2	33.1	33.0	32.9	32.8	32.6
6.4	32.5	32.4	32.3	32.2	32.1	32.0	31.9	31.8	31.7	31.6
6.5	31.5	31.4	31.3	31.2	31.1	31.0	30.9	30.8	30.6	30.6
6.6	30.5	30.4	30.2	30.1	30.0	30.0	29.8	29.8	29.6	29.6
6.7	29.5	29.4	29.3	29.2	29.1	29.0	28.9	28.8	28.7	28.6
6.8	28.5	28.4	28.3	28.2	28.1	28.0	27.9	27.8	27.8	27.7
6.9	27.6	27.5	27.4	27.3	27.2	27.1	27.0	27.0	26.9	26.8
7.0	26.7	26.6	26.5	26.4	26.3	26.2	26.2	26.1	26.0	25.9
7.1	25.8	28.8	25.7	25.6	25.5	25.4	25.3	25.2	25.2	25.1
7.2	25.0	24.9	24.8	24.8	24.7	24.6	24.5	24.4	24.4	24.3
7.3	24.2	24.1	24.0	24.0	23.9	23.8	23.8	23.7	23.6	23.5
7.4	23.4	23.4	23.3	23.2	23.2	23.1	23.0	22.9	22.9	22.8
7.5	22.7	22.6	22.6	22.5	22.4	22.4	22.3	22.2	22.2	22.1

7.6	22.0	21.9	21.9	21.8	21.7	21.7	21.6	21.5	21.5	21.4
7.7	21.3	21.3	21.2	21.1	21.1	21.0	20.9	20.9	20.8	20.7
7.8	20.7	20.6	20.6	20.5	20.4	20.4	20.3	20.2	20.2	20.1
7.9	20.0	20.0	19.9	19.9	19.8	19.8	19.7	19.6	19.6	19.5
8.0	19.4	19.4	19.3	19.3	19.2	19.2	19.1	19.0	19.0	18.9
8.1	18.9	18.8	18.8	18.7	18.6	18.6	18.5	18.5	18.4	18.4
8.2	18.3	18.3	18.2	18.2	18.1	18.0	18.0	17.9	17.9	17.8
8.3	17.8	17.7	17.7	17.6	17.6	17.5	17.5	17.4	17.4	17.3
8.4	17.3	17.2	17.2	17.1	17.1	17.0	17.0	16.9	16.9	16.8
8.5	16.8	16.7	16.7	16.6	16.6	16.5	16.5	16.4	16.4	16.3
8.6	16.3	16.2	16.2	16.2	16.1	16.1	16.0	16.0	15.9	15.9
8.7	15.8	15.8	15.8	15.7	15.7	15.6	15.6	15.5	15.5	15.4
8.8	15.4	15.4	15.3	15.3	15.2	15.2	15.2	15.1	15.1	15.0
8.9	15.0	14.9	14.9	14.9	14.8	14.8	14.7	14.7	14.7	14.6
9.0	14.6	14.5	14.5	14.5	14.4	14.4	14.3	14.3	14.3	14.2
9.1	14.2	14.2	14.1	14.1	14.0	14.0	14.0	13.9	13.9	13.8
9.2	13.8	13.8	13.7	13.7	13.7	13.6	13.6	13.6	13.5	13.5
9.3	13.5	13.4	13.4	13.4	13.3	13.3	13.2	13.2	13.2	13.1
9.4	13.1	13.1	13.0	13.0	12.0	12.9	12.9	12.9	12.8	12.8
9.5	12.8	12.7	12.7	12.7	12.6	12.6	12.6	12.6	12.5	12.5
9.6	12.5	12.4	12.4	12.4	12.3	12.3	12.3	12.2	12.2	12.2
9.7	12.2	12.1	12.1	12.1	12.0	12.0	12.0	11.9	11.9	11.9
9.8	11.8	11.8	11.8	11.8	11.7	11.7	11.7	11.6	11.6	11.6
9.9	11.6	11.5	11.5	11.5	11.5	11.4	11.4	11.4	11.3	11.3
10.0	11.3	11.3	11.2	11.2	11.2	11.2	11.1	11.1	11.1	11.0
10.1	11.0	11.0	11.0	11.0	10.9	10.9	10.9	10.8	10.8	10.8
10.2	10.8	10.8	10.7	10.7	10.7	10.6	10.6	10.6	10.6	10.6
10.3	10.5	10.5	10.5	10.5	10.4	10.4	10.4	10.4	10.3	10.3
10.4	10.3	10.3	10.2	10.2	10.2	10.2	10.2	10.1	10.1	10.1
10.5	10.1	10.0	10.0	10.0	10.0	10.0	9.9	9.9	9.9	9.9
10.6	9.8	9.8	9.8	9.8	9.8	9.7	9.7	9.7	9.7	9.6
10.7	9.6	9.6	9.6	9.6	9.6	9.5	9.5	9.5	9.5	9.4
10.8	9.4	9.4	9.4	9.4	9.4	9.3	9.3	9.3	9.3	9.2
10.9	8.2	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.1	9.1
11.0	9.0	9.0	9.0	9.0	9.0	8.9	8.9	8.9	8.9	8.9
11.1	8.9	8.8	8.8	8.8	8.8	8.8	8.8	8.7	8.7	8.7
11.2	8.7	8.7	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.5
11.3	8.5	8.5	8.5	8.5	8.4	8.4	8.4	8.4	8.4	8.4
11.4	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.2	8.2	8.2
11.5	8.2	8.2	8.2	8.2	8.1	8.1	8.1	8.1	8.1	8.1
11.6	8.0	8.0	8.0	8.0	8.0	8.0	8.0	7.9	7.9	7.9
11.7	7.9	7.9	7.9	7.8	7.8	7.8	7.8	7.8	7.8	7.8
11.8	7.8	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.6	7.6

11.9	7.6	7.6	7.6	7.6	7.6	7.6	7.5	7.5	7.5	7.5
12.0	7.5	7.5	7.5	7.4	7.4	7.4	7.4	7.4	7.4	7.4
12.1	7.4	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.3	7.2
12.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.1	7.1
12.3	7.1	7.1	7.1	7.1	7.1	7.1	7.0	7.0	7.0	7.0
12.4	7.0	7.0	7.0	7.0	7.0	7.0	6.9	6.9	6.9	6.9
12.5	6.9	6.9	6.9	6.9	6.8	6.8	6.8	6.8	6.8	6.8
12.6	6.8	6.8	6.8	6.8	6.7	6.7	6.7	6.7	6.7	6.7
12.7	6.7	6.7	6.7	6.6	6.6	6.6	6.6	6.6	6.6	6.6
12.8	6.6	6.6	6.6	6.6	6.5	6.5	6.5	6.5	6.5	6.5
12.9	6.5	6.5	6.5	6.5	6.4	6.4	6.4	6.4	6.4	6.4
13.0	6.4	6.4	6.4	6.4	6.4	6.4	6.3	6.3	6.3	6.3
13.1	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.2	6.2	6.2
13.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
13.3	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1	6.1
13.4	6.1	6.1	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
13.5	6.0	6.0	6.0	6.0	6.0	6.0	5.9	5.9	5.9	5.9
13.6	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.9	5.8
13.7	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8	5.8
13.8	5.8	5.8	5.8	5.8	5.8	5.7	5.7	5.7	5.7	5.7
13.9	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.7	5.6
14.0	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
14.1	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.5	5.5
14.2	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
14.3	5.5	5.5	5.5	5.5	5.4	5.4	5.4	5.4	5.4	5.4
14.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
14.5	5.4	5.4	5.4	5.4	5.4	5.4	5.3	5.3	5.3	5.3
14.6	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3
14.7	5.3	5.3	5.3	5.3	5.3	5.3	5.2	5.2	5.2	5.2
14.8	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
14.9	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
15.0	5.2	5.2	5.2	5.1	5.1	5.1	5.1	5.1	5.1	5.1
15.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
15.2	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
15.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15.4	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15.6	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
15.7	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
15.8	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
15.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
16.0	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
16.1	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
16.2	4.9	4.9	4.9	4.8	4.8	4.8	4.8	4.8	4.8	4.8

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